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Application Guide for Transformers

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UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

July 25, 1961

TO : All Electric Borrowers

SUBJECT: REA Bulletin 161-22, Application Guide for Transformers

Attached is a copy of REA Bulletin 161-22, Application Guide for Transformers.

This bulletin deals with the installation and operation of distribution and substation transformers. Portions of the bulletin are revisions of material previously published in Bulletin 61-9, Parallel Connection of Distribution Transformers and Bulletin 169-20, Transformer Problems.

New material includes sections on selection, installation, and loading of transformers; on connectors and terminals; and on special transformers.

This bulletin supersedes REA Bulletins 61-9 and 169-20.

Richard A. Dell

Acting Administrator

Attachment

I

TABLE OF CONTENTS

		Page
	INTRODUCTION	1
I.	SELECTION OF TRANSFORMERS	2
II.	INSTALLATION	5
	Location	5
	Cluster Mounting	5
	Jumpers	7
III.	POLARITY	10
IV.	CONNECTIONS FOR MULTI-PHASE SERVICE	13
	Wye-Delta Connection For 240 Volt Service	15
	Wye-Delta Connection For 120/240 Volt Service	16
	Wye-Wye Connection For 120/208 Volt Service	17
	Open Wye-Open Delta Connection	18
	Delta-Delta Connection	19
V.	PARALLEL CONNECTIONS	20
VI.	BANKING	25
VII.	LOADING	27
VIII.	PROTECTION	35
	Lightning Protection	35
	Overcurrent Protection	36
	Protection from Birds and Animals	37
IX.	CLAMPS, CONNECTORS AND TERMINALS	38
X.	SPECIAL TRANSFORMERS	42

Index:

TRANSFORMERS
  Application Guide

CONSTRUCTION
  Installation of Transformers

UNITED STATES DEPARTMENT OF AGRICULTURE
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FOREWORD

Transformers represent a substantial part of the total investment in rural power distribution systems. With a full load efficiency of from 97 to 99 percent, the transformer is probably the most efficient device for converting energy which man uses; yet, the total of energy lost in transformers is a large part of all rural distribution system losses. Under the right conditions, transformers can operate continuously for many years without requiring removal for repair or servicing; but because of growing loads, they are moved and replaced more often than almost any other equipment on the line. The long-range plans of many REA borrowers show that the money which will be spent in the future for the purchase and installation of transformers will be approximately as much as that to be spent on all other distribution line construction and improvement combined.

In short, the purchase, installation, and use of transformers is of economic importance from the standpoint of both investment and operating expenditures. This bulletin discusses a number of problems peculiar to transformers, both distribution and substation, used by REA borrowers. It is not intended to apply to instrument transformers or to step-up substation transformers installed at generating stations.

This bulletin supersedes REA Bulletins 61-9, Parallel Connection of Distribution Transformers and 169-20, Transformer Problems.

CHAPTER I

SELECTION OF TRANSFORMERS

Single Phase or Three Phase?

Three-phase substation transformers are priced somewhat lower than the equivalent three single-phase transformers. Although the price difference varies with size and voltage, it can amount to a considerable saving when transformers are purchased for one or more substations.

In the early days of the REA program, the use of three-phase substation transformers was strongly discouraged for the following reasons:

1. In the radial system, failure of a three-phase substation transformer could cause an extended outage of the entire substation area. Outages from failure of single-phase transformers could be corrected by use of a spare transformer in the substation or, in the absence of a spare, by reconnection of the two remaining transformers.

2. There was little or no interconnection between power sources to provide an alternate supply of power.

3. The condition of roads and lack of suitable transportation equipment often made it impossible to bring in a spare transformer within a reasonable time.

In many instances, these objections are no longer valid. The borrower now can often provide standby service, either from alternate power sources, by mobile substations, or by facilities to move a spare transformer into place quickly. In such cases there is no objection to the use of three-phase substation transformers.

The use of three-phase distribution transformers is not recommended. Most three-phase banks must also supply some single-phase load. This may make it desirable to use a transformer of larger kva capacity in one of the phases. Also, when transformers are removed from a three-phase installation for any reason, single-phase transformers can be reused at single-phase installations, while three-phase transformers may become surplus. The saving in the purchase of three-phase distribution transformers is not sufficient to offset the additional costs of larger storeroom stocks and loss of flexibility.

Taps

The addition of taps in the primary winding of a transformer makes it possible to adapt the transformer to a range (usually 10 percent) of supply voltages. Although the transformer must be de-energized when the tap position is changed, this feature is quite valuable in substation transformers.

In distribution transformers, particularly the smaller sizes, it is questionable whether taps are worth the additional cost, which is about 10 percent of the transformer price. The big voltage problem on a distribution system is usually that of voltage swing between peak load and light load rather than a voltage which is always too high or too low. The taps are of no help in correcting voltage swing. Taps which are not used are an unnecessary expense. Furthermore, the tap changer itself is a possible source of trouble.

Regulating Transformers

Three-phase substation transformers can be obtained with load tap changing equipment which performs the function of a substation voltage regulator. This equipment is housed in the transformer tank and operates in a manner similar to a three-phase regulator; that is, voltage output from one phase is used to control the tap settings on all three phases simultaneously. This arrangement may cost less than the transformer with three separate single-phase regulators but has the following disadvantages:

1. The transformer must be de-energized whenever inspection or maintenance work is needed on the tap changing mechanism.

2. A failure of the tap changer requires that the transformer be removed from service.

3. Three-phase control of regulation is not as good as single-phase control when supply voltages are unbalanced or when peak loads do not occur on all phases at the same time.

Some manufacturers have put on the market load tap changing transformers which use single-phase control of the tap changers and which are equipped with by-pass switches to permit maintenance of the tap changers while the transformer is energized. These features eliminate many of the objections to load tap changing transformers.

Regulating transformers in the smaller, pole type, distribution sizes are a relatively new development. They are discussed in the chapter on Special Transformers.

Type of Cooling

All pole-type transformers and most substation transformers used on rural systems are the oil-immersed, self-cooled (OISC) type. This design depends on the oil to transfer the heat from the core and coil of the transformer to the tank walls or cooling tubes where it is passed into the surrounding air. This is possible because circulating currents are set up in the oil by temperature differences and because of the natural circulation of air around the outside of the transformers. On large substation transformers, this cooling process can be accelerated by the use of forced air (FA) in which fans are used to blow air over the cooling tubes; by forced oil in which an oil pump is used to speed up the circulation of the oil; or by a combination of the two. (FOA) Water is occasionally used instead of air for the outside cooling medium. These forced cooling methods can be obtained - at additional cost - to make it possible for the transformer to carry a higher kva than when operating as a self-cooled transformer. This is useful when space and weight limitations are critical, such as in a mobile substation. It is sometimes possible to add these auxiliary cooling devices to an existing transformer to increase the capacity. It should be pointed out, however, that this uprates the kva of the transformer only in the sense that it can carry additional load without overheating. The windings are the same; and since load losses vary approximately with the square of the load, the efficiency of the transformer will drop at the higher loads.

CHAPTER II

INSTALLATION

This chapter deals only with the installation of distribution transformers. Substation transformers should be installed in accordance with the plans and specifications for the particular substation. Refer to REA Bulletin 65-1, "Guide for the Design of Substations for Electric Borrowers."

Location

Distribution transformers should be located as close to the load as is practical. Because of the larger currents involved, voltage drop in the secondary conductor is much greater than in a corresponding length of primary conductor. REA recommends that the total of voltage drops in the transformer, secondary and service, at peak load be no greater than five percent. (Six volts on a 120-volt base. Refer to REA Bulletin 169-27.) A typical transformer, when carrying its rated load, will have a voltage drop of 2.0 to 3.0 percent. Since it is quite possible for a transformer to supply much more than its nameplate rating for short periods without damage, it may be that at peak load almost all of the allowable voltage drop takes place in the transformer itself. Unless the transformer is quite close to the load, there will be excessive voltage drop in the transformer and secondary circuit.

The transformer or transformers, together with arresters, cutouts, jumpers, and conductors, must be located on the pole so as to provide adequate climbing space. The standard REA transformer assembly drawings will fit most applications. Sometimes, however, conditions require the use of special assemblies. In designing such assemblies, the conductor separation, clearances, and climbing spaces should meet all requirements of the National Electrical Safety Code and state and local codes.

Transformers serving industrial plants or other loads where smoke, dust, or other contamination is present should, if possible, be located on the windward side of the plant. The accumulation of such materials on the transformer can cause bushing flashover and corrosion of the tank and other metal parts of the assembly.

Cluster Mounting

Banks of two or three transformers may be mounted either on crossarms or on special pole brackets for cluster mounting. For reasons of economy and appearance, cluster mounting has in many areas become the prevailing method. Although it is possible to use cluster mounting for banks as large as three 500 kva transformers on a single pole, such extremes of pole loading are usually

not practical. As a general rule, it is recommended that banks larger than three 100 kva transformers be mounted on platforms or on concrete pads on the ground. The amount of weight which can be put on a pole depends not only on the strength of the pole but also on the condition of the soil which must be firm enough to prevent the pole from sinking into the ground and to hold the pole in a vertical position. In sandy or marshy soils, concrete or other reinforcing may be needed under or around the pole.

Because of the better distribution of weight in a cluster mounting, it is possible to hang a greater total weight of transformers on a given pole than if crossarm mounting is used. In order to take advantage of this, however, the pole must be straight and should be set without rake. The following table shows the maximum size of transformer which should be installed in cluster mounting of either two or three transformers on a pole. If the transformers in a bank are of different sizes, the kva rating of the largest transformer will control. As materials and manufacturing techniques have improved over the years, transformer weights have been progressively reduced. To allow for this, Table I shows two different age groups of transformers.

TABLE I

Maximum Size of Transformer for Cluster Mounting

Length and Class of Pole	Maximum Size - Largest Transformer in Bank - KVA	
	Modern Transformer*	Old Transformer*
35-6	25	15
35-5	50	25
35-4	75	50
35-3	100	75
40-6	25	15
40-5	37½	25
40-4	50	37½
40-3	100	50

* "Modern transformer" refers to transformers having wound cores made from oriented steel. It includes practically all transformers built since 1950 and some makes built in earlier years.

Jumpers

The common material for transformer primary jumpers and grounding loops is 6 AWG bare, soft-drawn (annealed) copper. This wire is durable and easy to handle. It has sufficient conductivity for the primary currents of transformers up to and including 333 kva, although wire larger than No. 6 will sometimes be needed to give sufficient rigidity to the jumpers. Soft-drawn copper is less likely to break under vibration than either hard-drawn or medium-drawn copper. Where vibration is severe, even soft-drawn will eventually break but there are several steps which can be taken to reduce or delay jumper breakage:

1. Avoid sharp bends, especially near the ends where the jumper enters terminals or hot line clamps.

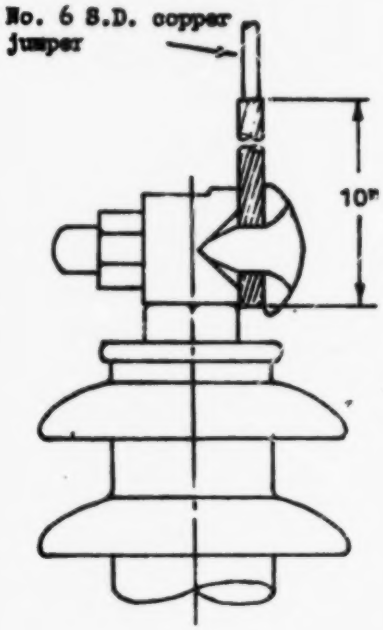
2. Do not pull the jumper tight. When one end of a jumper is attached to a span of conductor, slack must be provided to allow for movement of the conductor. This can be done by making two bends in a vertical plane or one bend in a horizontal plane. These should be wide, sweeping bends with a radius of at least six inches.

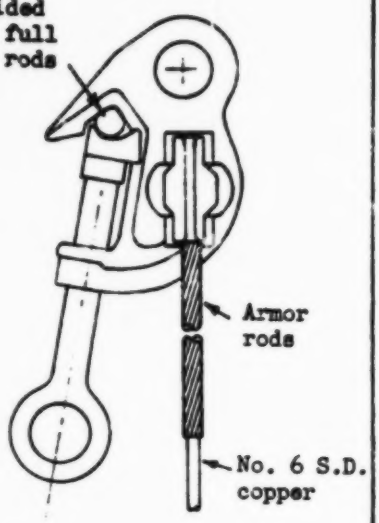
3. Do not bend the wire more than is necessary to get it out of the coil and into the desired shape of the jumper. Each time a wire is bent or straightened it becomes harder and more susceptible to vibration breakage.

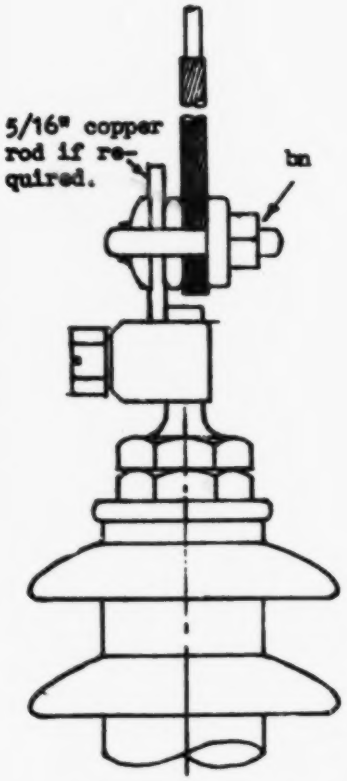
4. Use stranded wire which is more flexible than solid wire.

5. Use short (tap length) preformed armor rods over the ends of the jumper where it enters the transformer terminal and the tap connector of the hot line clamp. This is illustrated in REA Drawing A-3484 (Figure 1). The armor rods will spread the flexing of the jumper over several inches instead of having it concentrated at the point of connection. This will delay, if not prevent, the breaking of the jumper. Also, if a break eventually occurs inside the armor rods, they will hold the jumper in place and maintain electrical contact indefinitely.

Stranded aluminum wire is sometimes used for primary jumpers. It is also possible to make jumpers from short lengths of ACSR which might otherwise be good only for scrap. Solid aluminum is not recommended for jumpers because of its greater tendency to break from vibration. When primary conductors are ACSR, the use of aluminum primary jumpers eliminates one connection between unlike metals. Care must be used, however, to see that aluminum or ACSR jumpers are not put into unplated terminals of transformers, cut-outs, or arresters. Moisture will cause corrosion of the aluminum where it is in contact with a bare bronze terminal.







Notes:

1. Armor rods on both ends of jumpers must be vertical with slack between provided by a minimum of two right angle bends with a radius of not less than six inches.

2. Loop deadend clamp item "bn" is only required when the terminal will not accommodate # 6 S. D. solid copper wire with preformed armor rods

3. For open type cutouts not having satisfactory terminals, use a 1/0 split bolt connector with a 1/8" x 1 1/4" copper strap punched and bent to provide for the vertical attachment of the jumpers.

FIGURE 1

VIBRATION PROTECTION FOR JUMPERS

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		A-3484

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Secondary jumpers, where required, are usually covered and of the same material and conductivity as the secondary or service conductor.

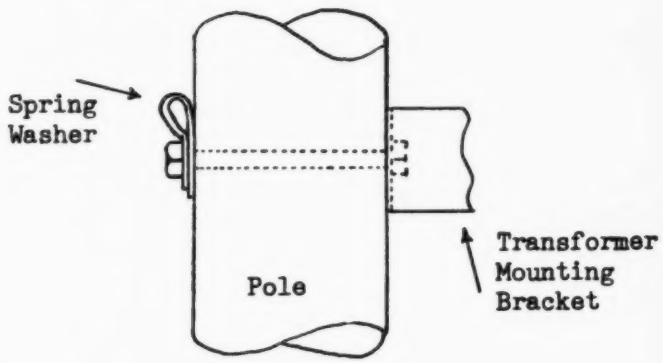
The breakage of ground jumpers is sometimes a serious problem. This is usually caused by pole shrinkage loosening the mounting bolts followed by high winds which rock the transformer back and forth on the pole. In standard REA single-phase transformer assemblies, the ground loop connects the system neutral, ground wire, secondary neutral bushing, and the tank ground connector in such a manner that at least two breaks must occur before the transformer is ungrounded. Nevertheless, in some localities, breaks in the ground jumpers are frequent enough so that other steps must be taken to prevent a potentially dangerous condition.

The use of spring washers (see Figure 2) on the mounting bolts will counteract the pole shrinkage and keep the bolts tight. This will reduce, but may not prevent entirely, the movement of the transformer with respect to the pole.

Additional ground connections will increase the safety factor. Single-bushing transformers have two tank ground connectors. A second ground loop can be formed using the extra tank ground connector. A flexible copper braid can be installed between the tank and the system neutral. A separate wire, connected to the neutral, can be wrapped around the top mounting bolt under the washers.

Such measures are not generally required but one or more of them should be considered where ground jumper breakage is severe.

FIGURE 2. SPRING WASHER USED TO KEEP TRANSFORMER MOUNTING BOLTS TIGHT



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CHAPTER III

POLARITY

Importance of Polarity

The polarity should be known when two or more single-phase transformers are operated in parallel or when they are connected in either a "V"-phase or a three-phase bank.

The polarity of a transformer is an indication of the relative instantaneous direction of current flow through the primary and secondary windings. It is designated as either additive polarity or subtractive polarity. Practically all modern transformers made in the United States have additive polarity if the high voltage rating is 8660 volts or less and the size is 200 kva or less. This means that pole-type transformers for use on 7200/12470 volt and 7620/13200 volt systems have additive polarity and that those for use on 14400/24900 volt systems have subtractive polarity. All transformers larger than 200 kva have subtractive polarity. For some older or rebuilt transformers, this rule may not apply. Generally the polarity will be shown on the nameplate; but if there is any doubt, polarity can be checked as follows:

Polarity Check for a Two-Bushing Transformer

Connect one high voltage terminal to the adjacent secondary terminal. (See Figure 3) Energize the high voltage winding with any convenient 60-cycle voltage such as 240 volts. Measure the voltage between the other high voltage terminal and its adjacent secondary terminal. If this voltage is more than that applied to the high voltage winding, the polarity is additive; if less, the polarity is subtractive.

Polarity Check for a Single-Bushing Transformer

Since a single-bushing transformer has one end of its high voltage winding permanently grounded to the tank and since the center of the secondary winding is usually also strapped to the tank, no external connection is needed. The primary winding should be energized with 240 volts applied between the high voltage terminal and the tank. (See Figure 4) Measure the voltage between the high voltage terminal and the secondary terminal on the left hand as one faces the secondary side of the transformer. If this voltage is higher than that applied to the high voltage winding, the polarity is additive; if lower, the polarity is subtractive.

For transformers rated 14400/24900 - 120/240 volts, the difference in voltage is slight; and when the test voltage is not steady or when a low-accuracy voltmeter is used, it may be difficult to get

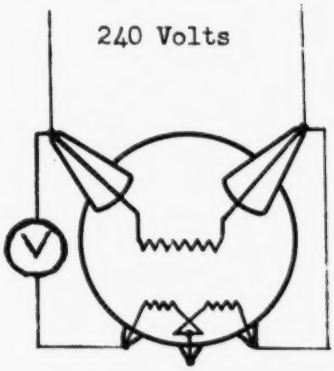

FIGURE 3. POLARITY CHECK, TWO-BUSHING TRANSFORMER

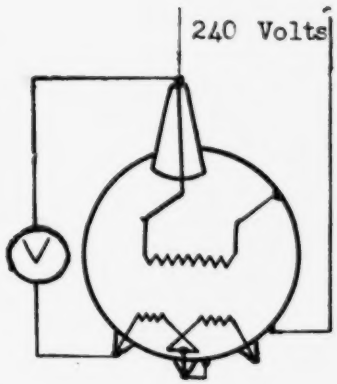

FIGURE 4. POLARITY CHECK, SINGLE-BUSHING TRANSFORMER

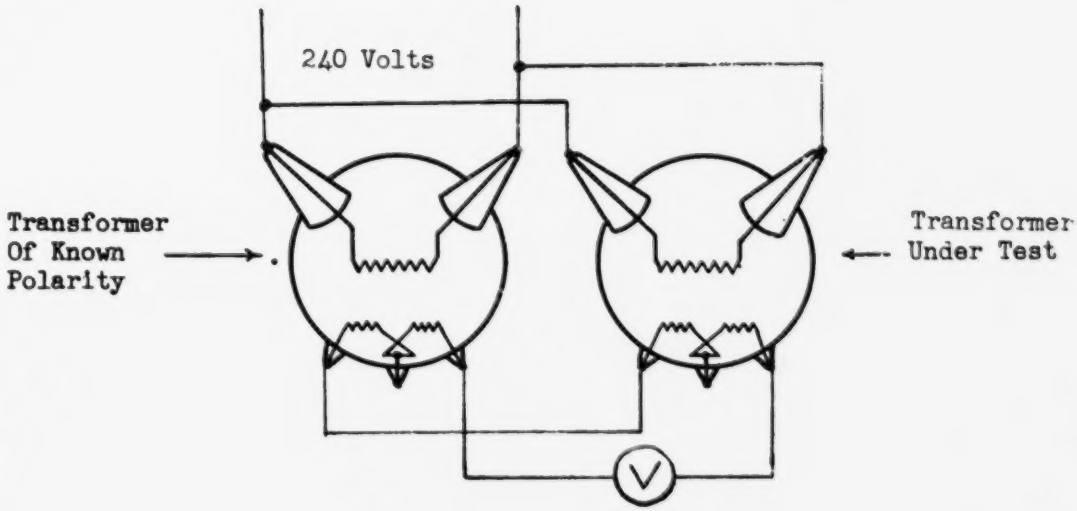

FIGURE 5 POLARITY CHECK BY COMPARISON WITH STANDARD TRANSFORMER

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a positive indication of polarity. When this happens, the alternate method described below may give better results.

Alternate Method of Polarity Check

This method can be used with either single or two-bushing transformers. It requires the use of another transformer of known polarity having the same voltage rating as the transformer to be tested. The primaries of the two transformers are connected in parallel as shown in Figure 5. The two left hand secondary terminals are connected, and the grounding straps are removed from the center secondary terminals of both transformers. A measured voltage such as 240 volts is applied to the primary side, and a voltmeter is connected between the right hand secondary terminals. A zero reading on the voltmeter indicates that the two transformers have the same polarity.

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CHAPTER IV

CONNECTION FOR MULTI-PHASE SERVICE

General

There are many ways in which two or three distribution transformers can be connected to supply three-phase power or a combination of single-phase and three-phase power. The connection which should be used will depend on the design of the primary line, on the type and voltage of the load to be served, and sometimes on the kind of transformers available. On the following pages are shown some of the more commonly used connections. The good features and the bad features of each are discussed. In order to simplify the drawings, fuses and lightning arresters are not shown.

Generally the transformers used in three-phase installations should be conventional transformers with two primary bushings. Single-bushing transformers have one end of the primary winding grounded to the tank and can be used only in banks where the primary is connected in grounded wye. Self-protected transformers should not be used in any bank where the secondary is connected in closed delta. Self-protected transformers and single-bushing transformers may be used in the wye-wye and open wye-open delta connections but are not recommended for other connections.

Transformers used together in banks should have identical voltage ratings and, if they have taps, should be set on the same tap position. Except in the seldom-used delta-delta connection, it is not necessary that the transformers have the same impedance. Normally, all transformers of a similar size and voltage rating will have the same polarity. If it should be found that one of the transformers to be used has opposite polarity either (but not both), its primary or secondary connections should be reversed.

With respect to the physical arrangement of transformers and jumpers, the connections shown in the following drawings are suitable for platform, ground, or cluster mounting. If the transformers are to be mounted on crossarms, a somewhat safer placement of the primary jumpers is obtained by reversing the connections to one of the transformers. For example, Figure 6 shows a wye-delta connection for 240 volt service. If both the primary and secondary connections to the right-hand transformer are reversed for crossarm mounting, the high voltage jumper will rise in an almost vertical line from the right-hand bushing to the outside phase conductor, C. This procedure has been followed in standard REA assembly drawings for crossarm mounting.

Connections for supplying 480 volt three-phase power are the same as those given for 240 volts. If 120/240 volt single-phase service

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is needed at the same location as a 480 volt three-phase load, it should be supplied from a separate distribution transformer and single-phase meter or from a 480-120/240 volt transformer connected to the 480 volt secondary.

Note that in all connections the secondary grounds are interconnected with the primary neutral, either through the secondary neutral or through a grounded secondary phase which serves as both ground and phase conductor. The primary neutral must be brought in to every transformer installation, even when the transformer primaries are connected in delta or in ungrounded wye. This is necessary for adequate lightning protection and for proper grounding. If motors and other equipment are to be grounded, the grounds should be interconnected with each other, with the secondary ground, and with the primary neutral. Refer to Bulletin 161-19, Grounding for Safety on Three-Phase Motor Installations.

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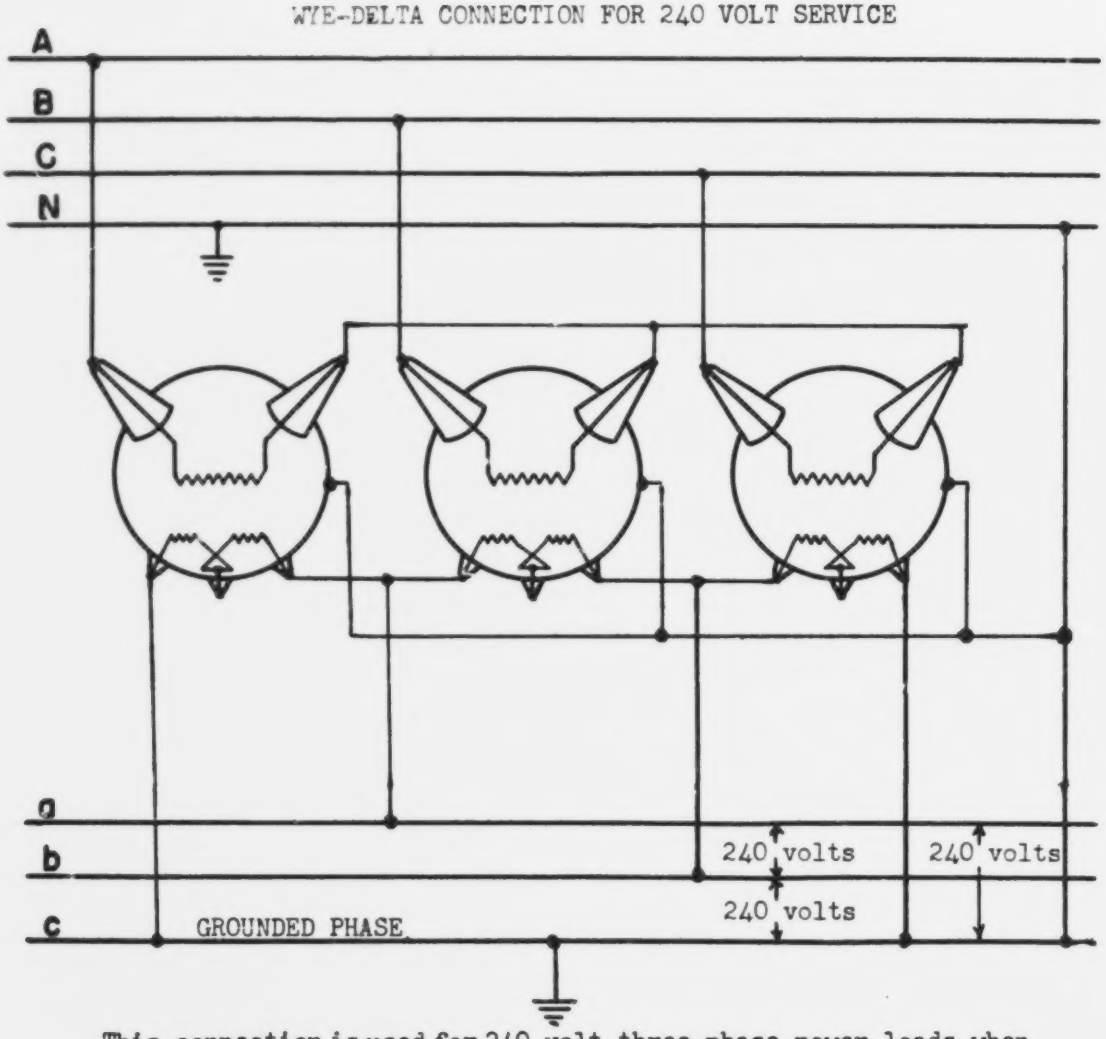
FIGURE 6

WYE-DELTA CONNECTION FOR 240 VOLT SERVICE



This connection is used for 240 volt three-phase power loads when single-phase 120/240 volt service is not required. It is not necessary that impedances or voltage ratios of transformers be matched exactly. The kva rating of the bank is three times the kva rating of the smallest transformer.

Note that this bank is <u>not</u> grounded on the primary side. If it were grounded, it would act as a grounding bank for the entire circuit and would be likely to burn out if a short circuit or an open circuit occurred on one of the phases between it and the substation.

The grounded secondary wire is not a neutral. It is a phase wire which operates at ground potential. In addition to carrying the phase current, it serves to interconnect the grounds at the meter and load with the primary neutral. Triplex cable may be used for the service drop with the bare wire being used for the grounded phase. The bare wire must have the same conductivity as the covered wires.

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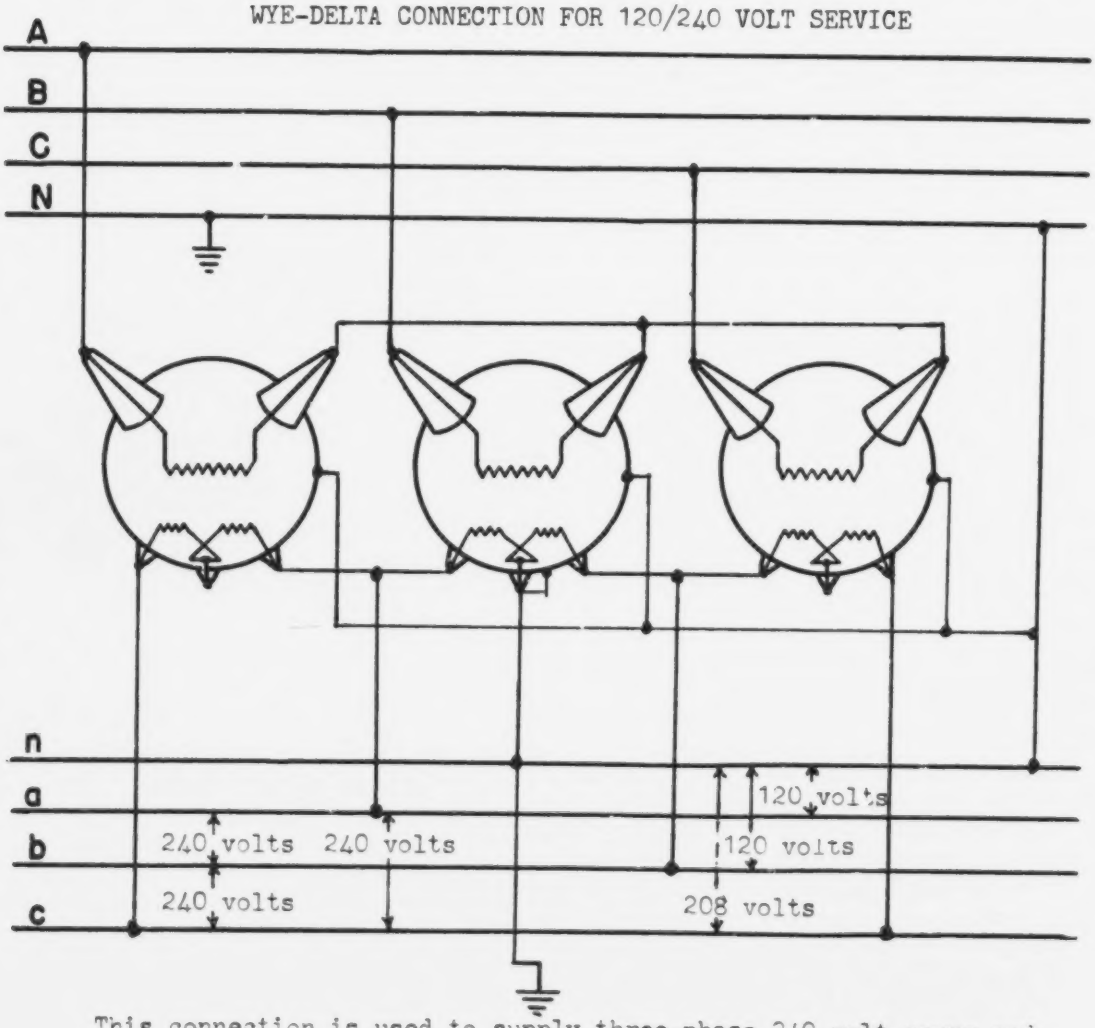
FIGURE 7

WYE-DELTA CONNECTION FOR 120/240 VOLT SERVICE



This connection is used to supply three-phase 240 volt power and single-phase 120/240 volt power. This bank must <u>not</u> be grounded on the primary side.

Each transformer will supply 1/3 of the three-phase load. The transformer with midtap on the secondary winding will supply about 2/3 of the single-phase load while each of the other transformers will carry approximately 1/3 of the single-phase load. If the single-phase load is small in relation to the three-phase load, all three transformers may be the same size. For larger single-phase loads, the center transformer may be larger than the others; but it should never be more than twice the size of either of the other transformers in the bank.

Note the "wild leg" (phase c) of the secondary has a potential of 208 volts to neutral and should not be used in the 120/240 volt circuit. It can be identified as the phase which is not connected to the center-tapped transformer.

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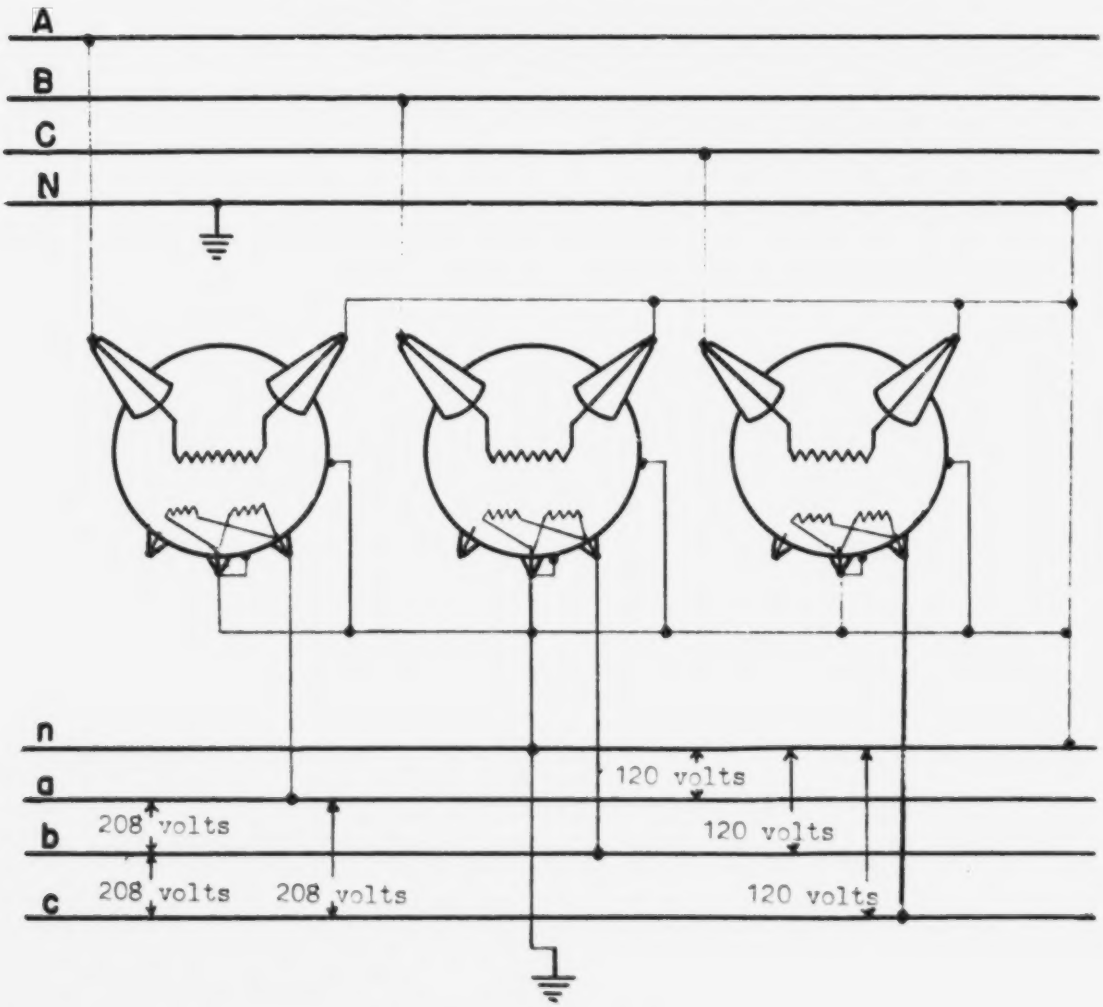
FIGURE 8

WYE-WYE CONNECTION FOR 120/208 VOLT SERVICE



This connection is used to supply 208 volt three-phase power and 120 volt single-phase power. The primary wye point of this bank must be tied to the system neutral and grounded. It must also be interconnected with the secondary neutral. If these connections are not made, dangerous voltages may develop on the secondary side.

It is not necessary that transformers be matched as to size, impedance, or exact voltage ratio. Each transformer will supply the single-phase load connected to it and 1/3 of the three-phase load. The secondary windings must be connected as shown to provide 120 volts.

Single-bushing transformers may be used if desired.

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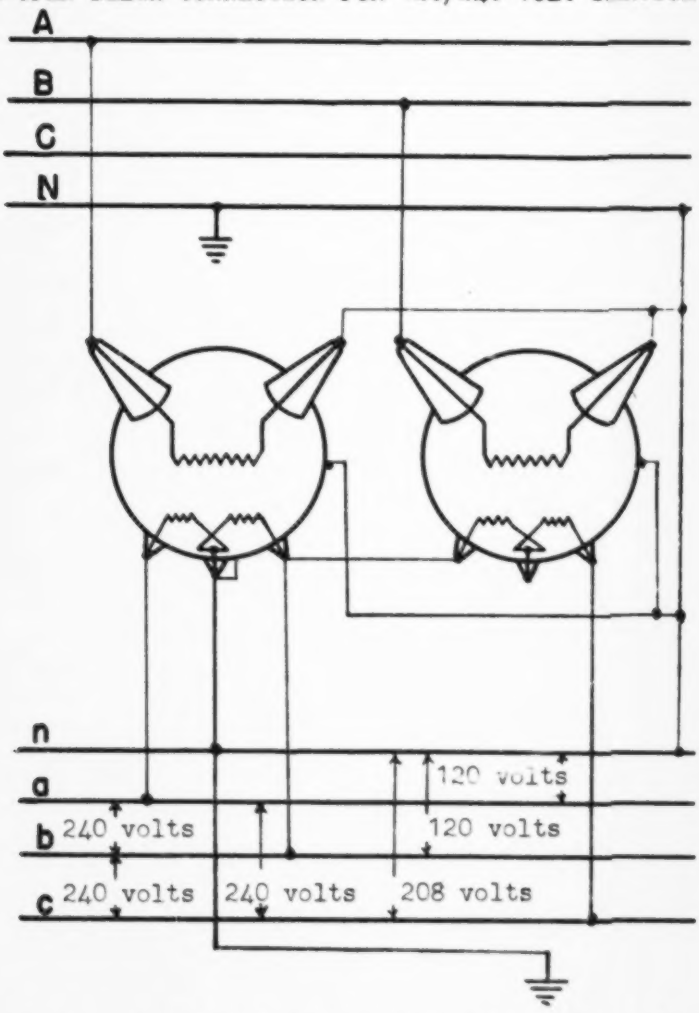
FIGURE 9

OPEN WYE-OPEN DELTA CONNECTION FOR 120/240 VOLT SERVICE



This connection is used where three-phase service is needed, but only two primary phases are available. It is also recommended for use on three-phase lines where a small three-phase load and a relatively large single-phase load are to be served from the same bank. In this latter case, the transformers are usually of different kva sizes. There is no limitation on ratio of two sizes that may be used.

Note that the primary neutral point is grounded.

Single-bushing transformers may be used if desired.

Note the "wild leg" (phase c) of the secondary has a potential of 208 volts to neutral and should not be used in the 120/240 volt circuit. It can be identified as the phase which is not connected to the center-tapped transformer.

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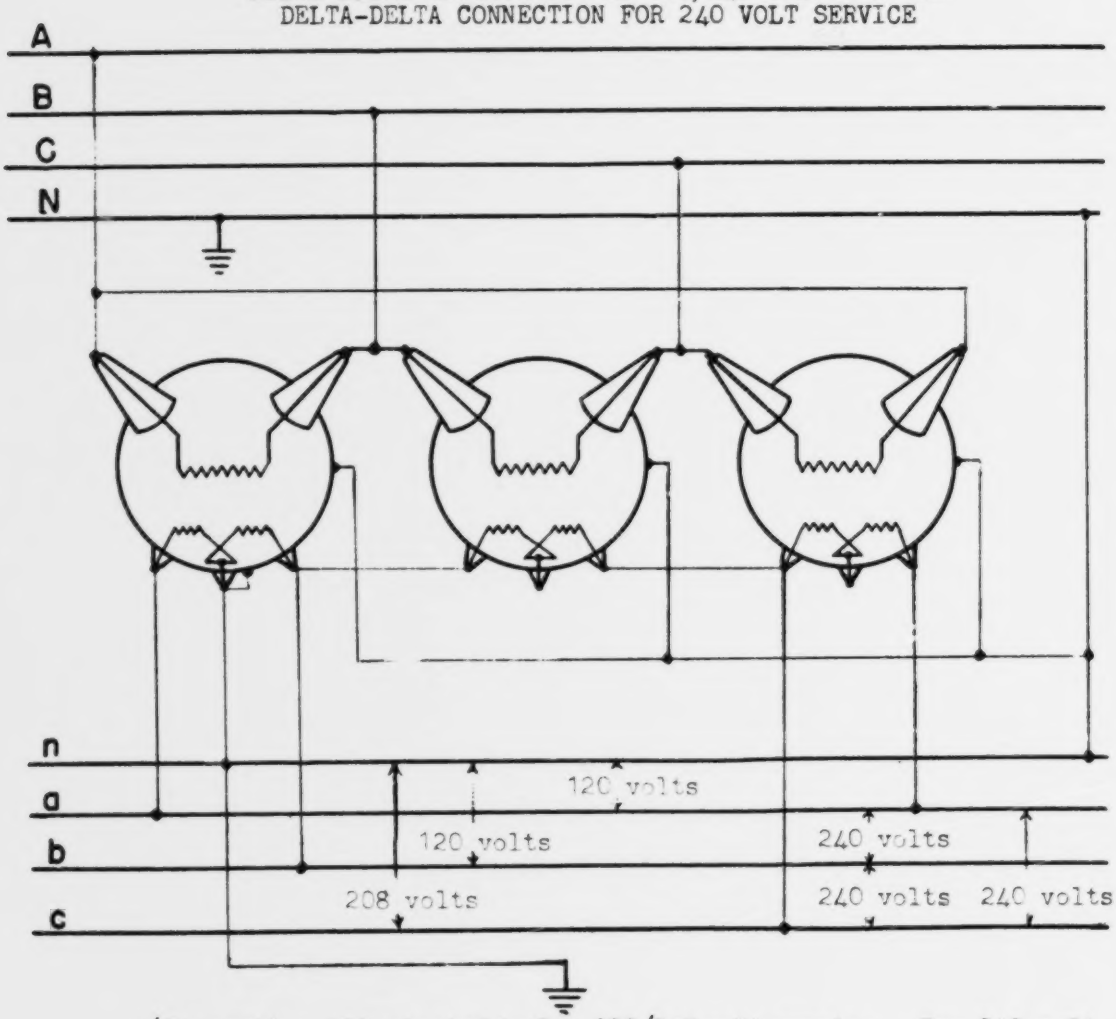
FIGURE 10

DELTA-DELTA CONNECTION FOR 120/240 VOLT SERVICE
DELTA-DELTA CONNECTION FOR 240 VOLT SERVICE



(Connection illustrated is for 120/240 volt service. For 240 volt service, eliminate secondary neutral and center tap to transformer; ground one secondary phase conductor and interconnect with primary neutral.)

These connections are seldom used by REA borrowers, but under certain conditions they may be needed. Two-bushing transformers with primary voltage ratings of 13,000, 13,800, and even 14,000 volts with proper tap setting can be connected in this way to 7,200/12,470 volt or 7,620/13,200 volt systems. For 2,300 volt delta systems, the connections are as shown above but without a primary neutral.

The transformers must be matched with regard to voltage ratios and percent impedance and tap settings; otherwise, excessive circulating currents may overheat or burn out transformers.

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CHAPTER V

PARALLEL CONNECTIONS

Parallel Connection of Distribution Transformers

Power distributors sometimes parallel small distribution transformers in order to use surplus stocks of these transformers in serving growing loads.

REA has not encouraged this practice because of several inherent disadvantages. For example, the no-load and full-load losses of two 3 kva transformers in parallel are about the same as for a single 10 kva transformer and, of course, are somewhat higher than the losses for the single 5 kva or 7½ kva for which they will substitute. Excessive losses may result if the parallel transformers have different percent impedances or are set on different tap positions so that they do not divide the load properly. It is also more difficult to arrange two transformers and their associated jumpers into a safe configuration on the pole.

Although these disadvantages exist, an increasing number of utilities are employing some method of paralleling in order to use the available stock of small sizes of transformers. If applied properly, paralleling may, in some cases, be preferable to the conversion or up-rating of transformers.

One common method of paralleling is to connect both primary windings in parallel and both secondary windings in parallel. This requires not only that the transformers have identical voltage ratings but that their percent impedances be very nearly identical. This method will permit two transformers of different kva ratings to be paralleled.

REA Drawing G110 (Figure 11) shows another method of paralleling which seems more applicable for rural use. Here the primary windings are in parallel, but the secondaries (each connected for 120 volts) are in series. This type of connection requires that the two transformers be of the same kva rating but does not require them to have the same impedance.

The connection shown is for two transformers having like polarity. If they have unlike polarity, there will be zero voltage between the "hot" secondary wires. This can be corrected by reversing the internal secondary connections of one of the transformers. This will not often be the case since all modern 7,200 and 7,620 volt pole-type transformers have additive polarity and all 14,400 volt transformers have subtractive polarity.

The mounting bracket shown in the drawing is designed to support two transformers about 120° apart on the pole. These brackets are

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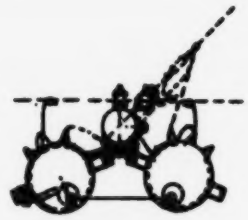
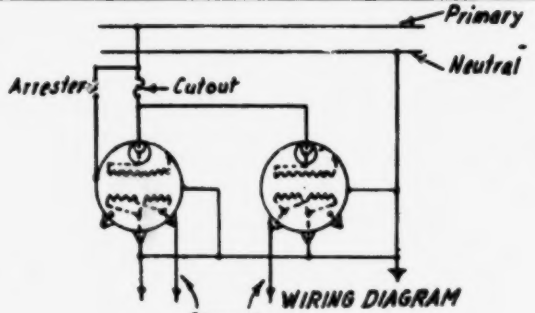
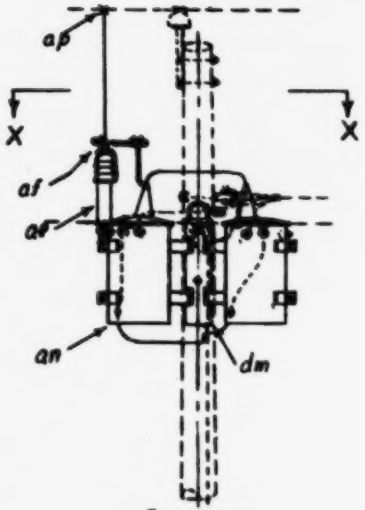


SECTION X-X

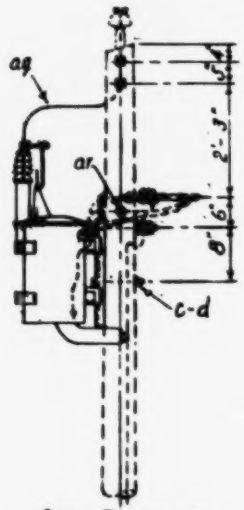


WIRING DIAGRAM

ITEM	QUAN.	MATERIAL
c	1	Bolt, machine, 5/8" x ... lg.
d	1	Washer, 2 1/4" x 2 1/4" x ...
p		Connectors, as required
ae	1	Lightning arrester
af	1	Cutout, fuse, single shot
an	2	Transformer, conventional
ap	1	Clamp, hot line, tap assembly
aq		Jumpers or leads as req'd.
dm	1	Bracket, transformer
ar	1	Wireholder



ELEVATION



SIDE ELEVATION

Notes:
Transformers must have identical voltage and KVA ratings, polarity and tap settings. If polarity is different there will be zero voltage between the hot service wires. In this case the internal secondary connections on one transformer must be reversed.

When service take-off is from side of pole opposite neutral, service should be deadended on pole below transformers.

FIGURE 11

7.2/12.5 KV. PRIMARY, 1-PHASE 2-WIRE, NEUTRAL GROUNDED PARALLEL CONNECTION OF CONVENTIONAL SINGLE PHASE TRANSFORMERS

Scale: 3/4"=1'-0"

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shown on page dm of the List of Materials Acceptable for Use on Systems of REA Electrification Borrowers. They are less expensive than the cluster mounts shown on the same page which will accommodate two or three transformers and which are intended for multiphase installations. Generally it is impractical to add a transformer in parallel without disturbing an existing installation. If the second transformer is located 90° to 120° from the first, it will often be right at the point of the service deadend. If the service is then dropped below the transformer, a great deal of ground clearance will be lost. If the second transformer is located 180° from the first, the jumper arrangement is cumbersome and hazardous. Some installations have been seen where a second high voltage jumper and hot-line clamp were used. This is an extremely dangerous practice since both transformers and jumpers remain energized until both jumpers have been removed.

The installation of a parallel transformer bank involves at least the temporary removal from the pole of the existing transformer. Since it is likely that this transformer will have been in service for a number of years, two reconditioned transformers should be installed and the original transformer returned to the shop for inspection and maintenance before it is reinstalled elsewhere on the system.

Parallel Connection of Substation Transformers

Parallel operation of substation transformers should be considered only as an emergency or temporary expedient. Two transformers will cost more than a single transformer of equivalent capacity; their combined losses are higher; and they require a more elaborate and expensive substation structure to accommodate them. For these reasons, the purchase of transformers for the purpose of parallel operation is not recommended.

Unlike pole-type transformers which can be operated with primaries in parallel and secondaries in series, substation transformers are connected in parallel on both the primary and secondary sides. This not only requires that the transformers have identical voltage ratings and that they be set on the same tap position but also that they have very nearly identical percent impedances.

It has generally been accepted that transformers can be paralleled successfully if the impedance of one does not differ by more than 7½ percent from the impedance of the other. For example, a transformer having an impedance of 6 percent can be paired with a transformer having an impedance anywhere between 5.55 percent (92.5% x 6%) and 6.45 percent (1.07.5% x 6%). These, however, are actual values rather than nameplate values. Under the applicable national standards, the manufacturer is allowed a tolerance of plus or minus 7½ percent from the established or nameplate impedance and is allowed a tolerance of 7½ percent between the impedance of transformers of identical design made at the same time. Since these

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manufacturing tolerances can account for all of the allowable variation in impedance, no attempt should be made to parallel transformers whose nameplate impedances are not identical.

When three single-phase transformers are to be added in parallel to three transformers in an existing substation, some alteration in the structure, buses, or concrete pad is often needed. The simplest arrangement has all six transformers in a single line with the paralleled pairs adjacent to each other (Figure 12). Usually, however, there is not enough room to make this arrangement and obtain the required separation between live parts. Probably the next best plan is two rows of three transformers each with paired transformers back-to-back with the high voltage bushings to the inside. In this way, the existing high voltage buses will usually serve both rows of transformers. A second set of low voltage buses should be added in parallel with the existing set as shown in Figure 13.

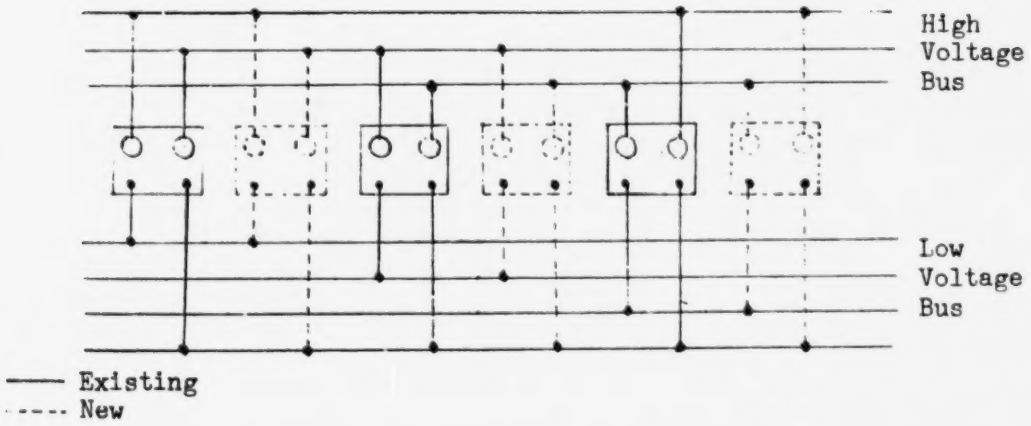

FIGURE 12. PARALLEL CONNECTION OF SUBSTATION TRANSFORMERS - IN LINE

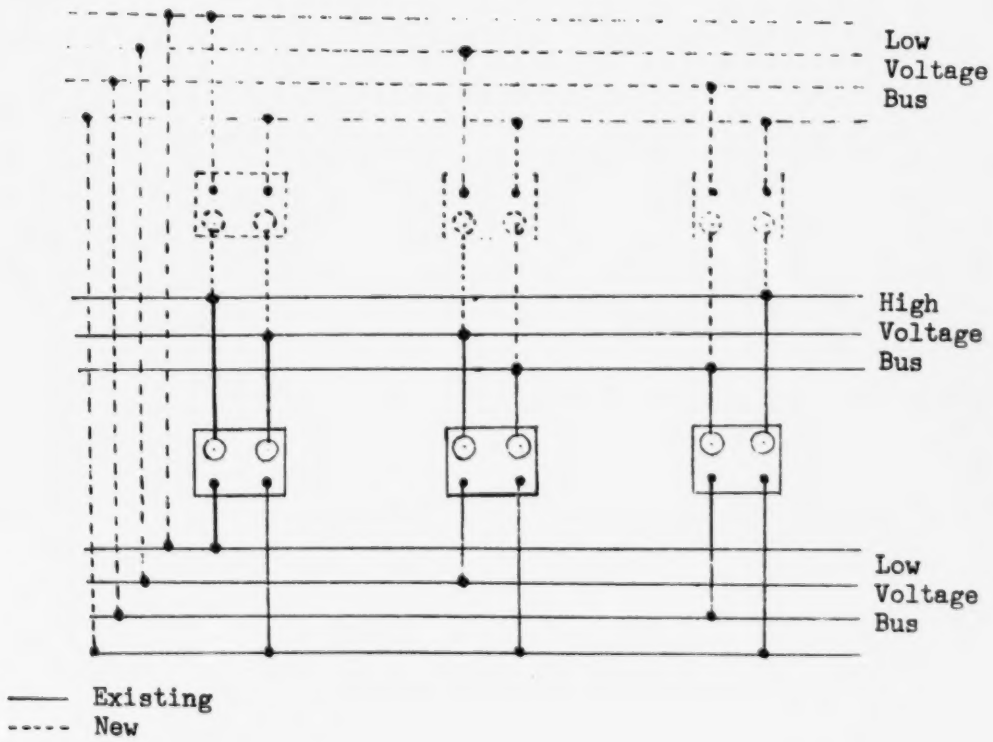

FIGURE 13. PARALLEL CONNECTION OF SUBSTATION TRANSFORMERS - BACK TO BACK

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CHAPTER VI

BANKING

Reasons for Banking

The term "banking" as used in this bulletin refers to the parallel connection of two or more single-phase distribution transformers on separate poles to serve a number of consumers from a continuous secondary underbuild.

In small towns, resort areas, and other locations where consumer density is high, banking of transformers offers some advantages. The better diversity of load obtained by serving a larger number of consumers from the common secondary makes possible less total kva of transformer capacity and a consequent reduction in the core losses. Service reliability is improved since, in the event of removal or failure of one transformer, the load can be supplied by the others. Better voltage regulation and reduction of light flicker is possible.

Disadvantages of Banking

In order that banked transformers will divide the combined load properly, their impedances must match. Also, to obtain the proper secondary protection, a sectionalizing system must be established for the secondary, either by the use of secondary fuses or by breakers in special network type transformers.

Banking will usually require more investment in secondary conductor than if the transformers are isolated. This will offset to some extent any saving resulting from the smaller transformer capacity.

Dangers of Banking

Although secondary banking has been used successfully by many electric utilities, it presents a very real hazard to linemen who are not thoroughly familiar with it and particularly to linemen who are accustomed to isolated transformer installations commonly used on rural lines.

A lineman, trained in the techniques of operating a system with isolated transformer installations, has come to expect that when a primary hot-line connection is removed the transformer, all of the related secondary and service conductors, and jumpers are safely de-energized. His work habits are controlled to a large extent by this concept. When he must work on a portion of the system having banked transformers and secondaries, this condition no longer exists. Removal of the primary line connection does not de-energize the transformer. Not only is the secondary side still energized from other transformers down the line, but the primary terminal and pri-

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mary jumper are at the full primary line voltage. The lineman may be fully aware of this; but under the stress of an emergency or merely from force of habit, he can slip into his old work habits with fatal results.

With careful planning, thorough training, competent supervision, and marking of the banked transformers with appropriate signs, the dangers can be reduced. Before a decision is made to bank transformers, however, a careful study should be made to find whether the benefits will be worth this extra effort and risk.

CHAPTER VII

LOADING

Determination of Allowable Loads

A transformer can supply a load well beyond its nameplate rating without burning out immediately. The amount of overload it can carry without damage depends on several factors, all of which are related to the temperature of the transformer under peak load conditions.

An oil-filled transformer is designed to give normal service life when supplying its rated load continually in an ambient air temperature which at no time exceeds 40 C (104 F) and which over any 24-hour period averages not more than 30 C (86 F). The transformer, of course, will not be operated under these exact conditions. The load is rarely constant but varies during the day. The temperature of the surrounding air will usually be lower but at some times of the year may be higher than the design figures. We can take advantage of these variations to increase the peak load above the rating of the transformer as long as the equivalent temperature of the hottest spot inside the transformer does not exceed for any 24-hour period the maximum temperature for which the transformer is designed. We cannot measure this hot spot temperature; but if we know the characteristics of the load and the air temperature, we can approximate the amount of overload which can be placed on the transformer without shortening its life. This is true for any size of transformer; however, for the small, pole-type transformer serving one or two consumers, it is not practicable to use recording meters to find the characteristics of the load. Other indicators; such as, the kwh consumption, a study of the connected load, or overload indicating devices mounted on the transformer, must be used to get an approximation of the peak demand on the transformer.

Oil Temperature

Some transformers rated 250 kva and above are equipped with dial type thermometers to indicate top oil temperature. Oil temperature alone is not an adequate guide for proper transformer loading because the oil temperature is lower than that of the winding. How much lower depends on the characteristics of the transformer and the amount of load it is carrying. For example, in a transformer loaded to its nameplate rating, the highest winding temperature may be 20 C above the oil temperature registered by the thermometer. In the same transformer loaded to 150 percent of its rating, the winding temperature may be as much as 40 C above the oil temperature. Thus, no single safe maximum oil temperature can be established since it must be related to the load on the transformer.

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Periodic observations of maximum thermometer readings are helpful in showing the trend of transformer loadings over a period of time, but they will not necessarily warn of dangerous overheating of the transformer windings.

Load Cycle

For substation transformers and for distribution transformers serving large loads, the following method can be used to determine the allowable overload. This is based on portions of the American Standards Association publication, "Guide for Loading Oil-Immersed Distribution and Power Transformers". The Guide may be purchased from the American Standards Association, Inc., 10 East Fortieth Street, New York 16, New York.

A load cycle or load curve for a typical 24-hour period can be obtained with a recording ammeter. The cycle will be irregular in shape such as that shown in Figure 14 and must be converted to an equivalent rectangular load cycle consisting of an initial load and a peak load.

Equivalent Peak Load

There is usually one time during the day when the load rises to a considerably higher level than at other times. The length of this peak is determined visually; and since the actual cycle does not rise and fall vertically before and after the peak, the decision as to the length may have to be somewhat arbitrary. It will usually be found, however, that a reasonably close approximation can be made of the period during which the major portion of the peak load occurs.

Once the length of the peak has been measured, the equivalent height of the peak (expressed as a percent of the transformer rating) must be determined. This can be done exactly by the root-mean-square method or can be approximated by inspection. To apply the root-mean-square method, the peak load period is divided into a number of shorter periods (such as 5 or 10 minutes) and the load for each period is found from the actual load cycle. If the lengths of these periods are designated as t_1, t_2, t_3, etc., and the loads for the respective periods are L_1, L_2, L_3, etc., then the equivalent peak load is equal to:

$$\sqrt{\frac{L_1^2 t_1 + L_2^2 t_2 + \ldots . L_n^2 t_n}{t_1 + t_2 + \ldots . . t_n}}$$

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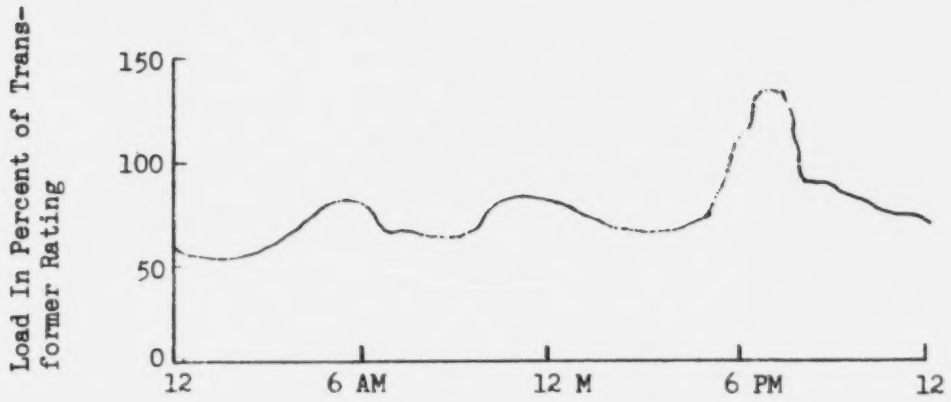

FIGURE 14. ACTUAL LOAD CYCLE

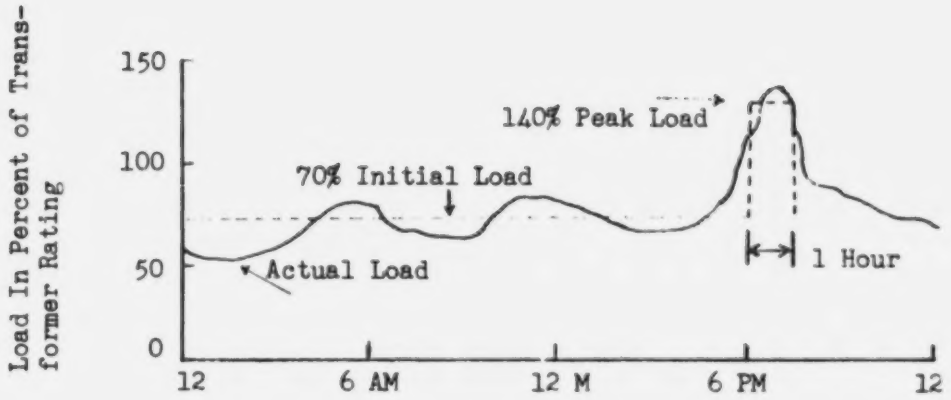

FIGURE 15. ACTUAL LOAD CYCLE CONVERTED TO EQUIVALENT LOAD CYCLE

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For most purposes, an approximation of the equivalent peak load by inspection will be close enough. To guard against overheating due to high, brief overloads during the peak period, the equivalent value for the peak load period should not be less than 90 percent of the integrated half-hour demand.

Equivalent Initial Load

The equivalent initial load is the root-mean-square load over a specified period preceding the peak load. This can be approximated by reading from the actual load cycle the average load for each one-hour interval of the 12-hour period preceding the peak load. If these average loads are designated L_1, L_2, L_3, ... L_{12}, then the equivalent initial load is equal to:

$$0.29 \sqrt{L_1^2 + L_2^2 + L_3^2 + \ldots\ldots L_{12}^2}$$

In Figure 15, the actual load cycle has been converted into an equivalent rectangular load cycle. In this example, the equivalent initial load was calculated to be 70 percent of the transformer rating and the peak load, with a length of one hour, was found to be an equivalent value of 140 percent of the transformer rating.

Allowable Overload

Table II shows the equivalent daily peak loads which can be supplied by self-cooled transformers under various conditions of initial load and ambient air temperature without any sacrifice of the normal life expectancy of the transformer. If the ambient temperature is 30 C (86 F) then the transformer in our example, with 70 percent initial load and a one-hour peak, could supply an equivalent peak load of as much as 1.49 times or 149 percent of the transformer rating for one hour without any loss of transformer life.

In order to determine the permissible overload at any future time, we must estimate what the ambient temperature will be at that time. The Weather Bureau of the U. S. Department of Commerce has prepared reports showing the average temperatures for the months of the year for various localities throughout the country. To allow for extremes of temperature, it is recommended that 5 C (9 F) be added to the monthly average and that the result be used as the ambient temperature for that month. The average monthly temperatures for an area may be obtained from the nearest local station of the Weather Bureau or they may be found in the series of Weather Bureau booklets, "Climates of the States". These booklets, one for each state, may be purchased individually or as a set from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. The price of the individual copies ranges from 10 to 25

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TABLE II
DAILY PEAK LOADS IN PER UNIT OF NAMEPLATE RATING TO GIVE NORMAL LIFE EXPECTANCY

Peak Load Time in Hours	Cooling — Self-Cooled or Water-Cooled (OA or OW) (1)																	
	Continuous Equivalent Load in Percent of Rated KVA Preceding Peak Load																	
	50 Percent						70 Percent						90 Percent					
	Ambient in Degrees C						Ambient in Degrees C						Ambient in Degrees C					
	0	10	20	30	40	50	0	10	20	30	40	50	0	10	20	30	40	50
½	2.00	2.00	2.00	1.89	1.70	1.52	2.00	2.00	1.95	1.78	1.60	1.41	2.00	1.99	1.82	1.64	1.46	1.24
1	2.00	1.88	1.73	1.58	1.41	1.23	1.95	1.80	1.65	1.49	1.32	1.14	1.86	1.70	1.55	1.39	1.20	0.99
2	1.76	1.64	1.51	1.37	1.22	1.06	1.72	1.59	1.46	1.32	1.16	0.99	1.66	1.53	1.39	1.24	1.08	0.90
4	1.54	1.43	1.33	1.19	1.06	0.92	1.52	1.41	1.29	1.17	1.04	0.89	1.50	1.39	1.26	1.13	1.00	-
8	1.41	1.30	1.19	1.08	0.96	0.84	1.40	1.30	1.19	1.07	0.95	0.83	1.39	1.29	1.18	1.06	0.94	-
24	1.33	1.22	1.11	1.00	0.89	0.78	1.33	1.22	1.11	1.00	0.89	0.78	1.33	1.22	1.11	1.00	-	-

(1) Subtract 5 C from each of the ambient column headings for water-cooled transformers. Minimum water temperature must be above zero C.

This table is reproduced from the Guide for Loading Oil-Immersed Distribution and Power Transformers, C57.92, copyrighted by ASA, copies of which may be purchased from the American Standards Association at 10 East 40 Street, New York 16, N. Y.

cents depending on the state.

A nomogram, Figure 16, has been included as an aid in converting temperature figures between the Centigrade and Fahrenheit scales.

Emergency Overloads

Transformers can be loaded beyond the levels shown in Table II with some loss in the expected life. The American Standards Association's "Guide for Loading Oil-Immersed Distribution and Power Transformers" includes charts and tables showing the overloads which can be handled with a moderate sacrifice of life expectancy. Although loading in this range should be avoided wherever possible, the ability of a transformer to supply such loads often provides a useful reserve of capacity for emergency conditions.

Table III shows the approximate loads which can be supplied by self-cooled transformers for a loss of life of not more than one percent for each loading. (It is assumed that the equivalent initial load does not exceed 70 percent of the nameplate rating.) Loads are expressed in per unit of the nameplate rating. Loading beyond twice the rating is not recommended.

TABLE III

Length of Peak Hours	Summer Peak	Winter Peak
½	2.0	2.0
1	1.9	2.0
2	1.6	2.0
4	1.4	1.7

It should be remembered that any overloading of a transformer, whether normal or emergency, involves not only the additional heat developed in the transformer but also added power losses and voltage drop. A transformer supplying twice its nameplate rating will have a voltage drop twice normal and copper losses four times normal. While these conditions can be tolerated during emergencies, they have an important bearing on any planned overloading.

Increased KVA Rating

The loading recommendations given in the American Standards Association's Guide and in this bulletin are quite conservative and are applicable to oil-filled transformers of any age. In the past few years, there has been a considerable improvement in the insulating materials used in transformers and a consequent improvement in the ability of transformers to withstand the heat developed during overload.

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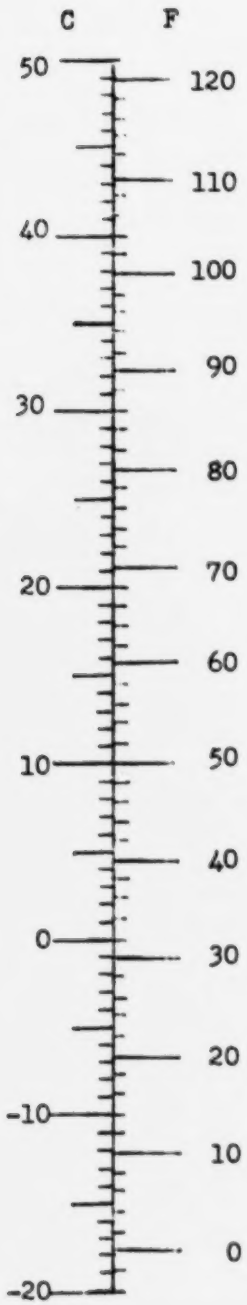

FIGURE 16. CHART FOR CONVERSION OF TEMPERATURES BETWEEN CENTIGRADE AND FAHRENHEIT SCALES

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There is no standard length of transformer life in terms of years of service. It is certainly true that a transformer which is never loaded to its full rated load will, on the average, have a longer life than if it were loaded daily to or above its rating. On the other hand, the additional investment and the greater core losses in the underloaded transformer add to the cost of operation. As a general rule, it is recommended that substation and distribution transformers not be changed out for larger sizes until the maximum loads permitted by the American Standards Association's Guide or the manufacturer's recommendations have been reached.

CHAPTER VIII

PROTECTION

This chapter applies to distribution transformers only. Refer to REA Bulletin 65-1 for recommended protection of substation transformers.)

Need for Protection

Transformers must be protected from lightning, from secondary short circuits, and from extreme overloads. The primary line must be protected against short circuits within the transformer itself so that a transformer failure will not cause an outage in the primary line.

Lightning Protection

In almost all portions of the United States, some means of protecting transformers from lightning is needed. Expulsion arresters, valve arresters, and gaps are used for this purpose. A discussion of the relative performance of arresters and gaps is given in REA Bulletin 45-3, "Summary Report of Field Study of Performance of Gaps and Lightning Arresters".

Arresters, both expulsion and valve, should have external air gaps at the top of the arrester. These gaps should be set not closer than the separation marked on the electrodes. Gaps set too close "spit", causing radio noise and ultimate destruction of the lightning arrester. The top gap is desirable because it prevents the internal parts of the arrester from being energized at full line voltage and thus eliminates one of the principal causes of radio noise. An external gap is needed on valve as well as on expulsion arresters to prevent line lockout if the internal gap should become shorted. Some arresters are equipped with automatic disconnecting devices to prevent lockouts.

Arresters or gaps should be located as close as possible to the transformers they protect. On a pole mounted transformer, the arrester or gap is installed on the transformer. When transformers are on crossarms or platforms, the gaps or arresters may be supported on crossarms above the transformers. If external primary fuses are used, the arresters should be connected to the line side rather than the transformer side of the fuse. Jumpers and ground leads to arresters should be as short as possible.

Gaps and arresters must be grounded to the transformer tank or to the transformer ground wire. All transformer or arrester ground wires must have at least the conductivity of No. 6 copper wire to comply with the requirements of the National Electrical Safety Code.

Overcurrent Protection

There are two ways in which a transformer can be damaged by large 60 cycle currents:

1. A direct secondary short circuit may produce currents high enough to wreck the coil with the magnetic forces developed between the windings. Transformers are required by A.S.A. standards, to withstand at least 25 times the rated full load current for two seconds. Newer pole-type transformers have an impedance of around two percent and can easily be subjected to currents greater than 25 times rated full load current. Manufacturers have recognized this and are beginning to design transformers capable of withstanding fault currents greater than the standard 25 times normal.

2. The transformer may be subjected to prolonged currents resulting from extreme overload or from high resistance secondary short circuits. These currents damage the transformer by raising the temperature until the insulation is destroyed.

Primary fuses, secondary fuses, and secondary breakers are used to protect transformers from overcurrents.

Secondary Breakers

The secondary breakers used in self-protected transformers are thermal relays. They are controlled jointly by the temperature of the transformer oil in which they are immersed and the heat generated by the transformer load current passing through the relay. When the resultant temperature reaches the danger point, the breaker opens and cuts the load from the transformer. Breakers generally are effective in preventing burnout from most types of overload but may cause problems by dropping overloads which the operator may wish to keep on the transformer. Provisions are sometimes made for by-passing the breaker or for up-rating it to a higher trip setting. These are emergency measures to enable the transformer to carry a greater overload than normal. Their use over an extended period may shorten the insulation life of the transformer.

Primary Fuses

Primary fuses may be located inside the transformer, as is the case in self-protected transformers, or outside the transformer. Internal fuses, being comparatively hard to replace, are large enough so that, in theory at least, they will blow only to protect the primary line against a failed transformer. Actually, however, they sometimes blow from lightning or other surges when there is no other apparent damage to the transformer.

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External primary fuses must protect the primary lines against short circuits within the transformer. Where there is no secondary breaker, they are often expected to protect the transformer against secondary short circuits or even overloads. While it is sometimes possible to select a size of fuse to do all of this, it will be so small that fuses will blow frequently from lightning, inrush currents, and other surges. On the other hand, if a fuse size is selected which is large enough to prevent these frequent outages, little or no protection is given against overload.

Dual element fuses, consisting of two fuse elements in a single fuse link have been designed to avoid this difficulty. One of the elements will melt under large short-time currents but will pass surges and inrush currents which are not large enough to damage the transformer. The other element is not affected by short-time currents but will melt under long-time overload currents. When properly selected according to the size of the transformer, these dual element fuses do a very acceptable job of protecting conventional transformers. Emergency overloads can be handled by substituting larger fuses, but it should be recognized that here, just as in the self-protected transformers, extended emergency overloads may shorten transformer life.

Protection from Birds and Animals

Birds and small animals sometimes cause flashover from transformer or arrester terminals, primary fuses, or leads to the tank. Transformers are now being made on which the covers are coated with vinyl or some other insulating material so as to prevent such faults. If this trouble is extensive on older transformers not having insulated covers, it may be desirable to cover live parts. Plastic or rubber covers for transformer bushings and terminals are available. It is also possible to changeout fuse supports and raise the external primary fuse high enough so that a bird or small animal on the top of the transformer cannot contact it easily.

CHAPTER IX

CLAMPS, CONNECTORS AND TERMINALS

Sources of Connection Trouble

Transformers must be connected to the primary conductor, to the secondary conductors, and to the ground wire, any of which may be made either of copper or aluminum. The terminals and ground wire connectors on the transformer are almost always made of bronze and are usually plated with some other metal.

A connection made by clamping a copper wire in a bronze terminal offers no problem regardless of whether the terminal is plated. It requires only that the wire be reasonably clean and that the terminal be tightened firmly.

There are two possible sources of trouble when aluminum wire (or ACSR) is placed in a bronze terminal - corrosion and "cold flow".

Corrosion

Electrolytic corrosion takes place when moisture is present at the junction of two different kinds of metal. The corrosion is most severe when the two metals are far apart in the electromotive series (as are aluminum and copper) or when salt or some other contamination is present. In an aluminum-to-copper connection, it is the aluminum which is damaged, never the copper. Since the transformer terminal is made of bronze, which is an alloy of copper, it behaves very much like copper when in contact with aluminum.

The most effective way of reducing this corrosion is to plate the bronze terminal with cadmium, nickel, tin, zinc, or some combination of these metals. These metals are much less corrosive to aluminum and as long as the plating is unbroken will give very good protection. In time, however, these platings may weather off and allow serious corrosion to start. Many older transformers, made before aluminum conductors came into general use, have no plating on the terminals. An aluminum conductor should never be connected in an unplated bronze terminal. If there is no plating or if the plating is damaged, a safe connection to aluminum can be made as shown in Figure 17. A short piece (3 to 4 inches) of copper wire is connected to the aluminum wire with an aluminum compression service connector. This sleeve type of connector is filled with a corrosion inhibitor which seals moisture out of the current path.

Cold Flow

"Cold flow" is a term used to describe the process by which a bolted aluminum-to-copper connection becomes loose and acquires a high resistance. This is particularly serious in the case of an aluminum

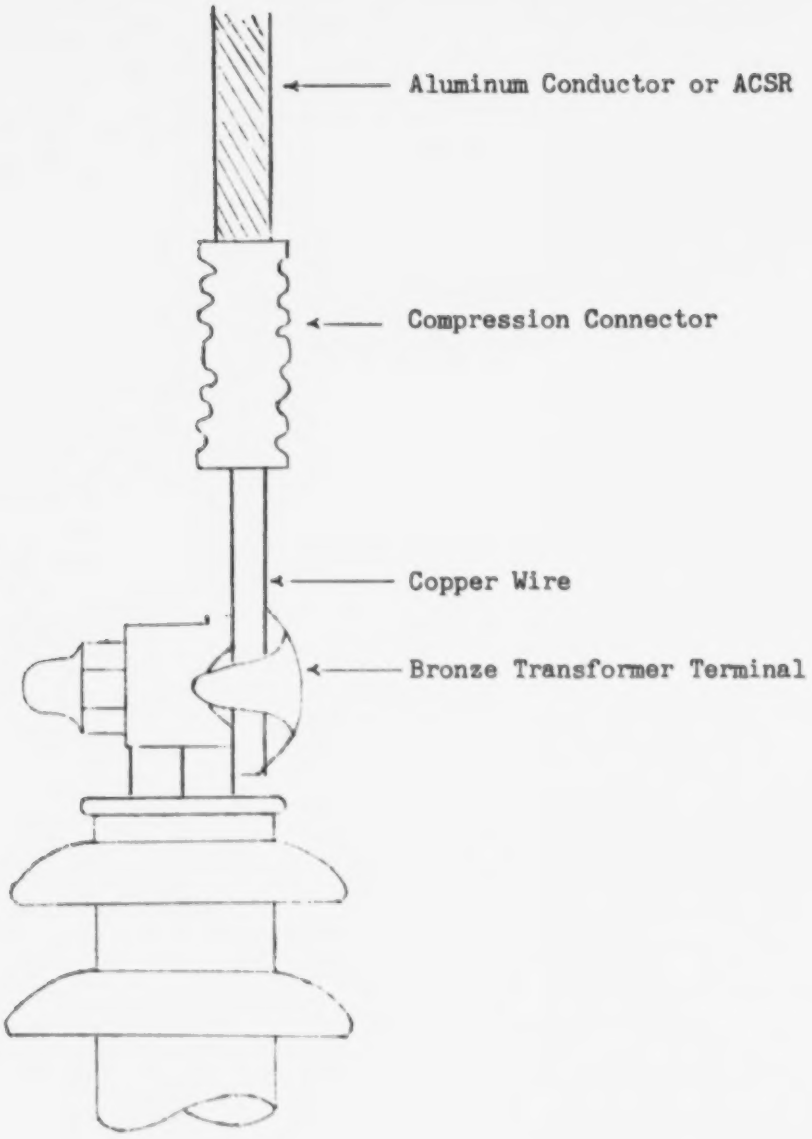

FIGURE 17. SAFE CONNECTION OF ALUMINUM CONDUCTOR TO UNPLATED BRONZE TERMINAL

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conductor in a bronze connector or terminal. Aluminum, being a soft metal, will flow or deform to some extent when squeezed by tightening the terminal; but unless the contact area is quite small, this flow is not enough to harm the connection.

A more serious flow occurs when the connection carries a current large enough to heat the joint. All metals expand when heated, but aluminum expands more than bronze for the same increase in temperature. The aluminum, since it is soft, cannot push the bronze out of the way and can expand only by flowing out the ends of the connector. The actual amount of flow is very little; but when the current drops and the joint cools, enough metal has flowed so that the connection is not quite as tight as before. This causes the resistance of the connection to increase slightly so that the next time load current is carried, more heat will be developed and the joint will be hotter than before, causing more flow of the aluminum. This load cycling, repeated over weeks, months, or years will loosen the connection until arcing occurs and the conductor is burned. The extreme heat developed in the joint at this time will destroy the plating on the bronze terminal or connector and leave a mottled appearance. This condition often leads to a false assumption that the plating failed first and allowed corrosion to ruin the connection.

Cold flow can be controlled by the use of properly designed connectors. Any hot-line clamp, bolted connector or compression connector intended for use on aluminum conductor should be made of aluminum or aluminum alloy. It should have a large contact area on the conductor. It is recommended that hot-line clamps be equipped with an enclosed coil spring to maintain a more even pressure on the conductor. Transformer manufacturers, not knowing whether a transformer will be used with copper or aluminum conductors, have customarily furnished transformers with plated bronze terminals and have attempted to limit cold flow by longer contact areas and by use of spring washers of one type or another. Manufacturers have hesitated to use aluminum terminals because of possible corrosion damage from copper conductor, but a great deal of experimental work is being done which may lead to the use of aluminum for this purpose.

Clean Connections

Any connection to aluminum conductor should be made only after the conductor is thoroughly cleaned. The aluminum oxide which is present even on new conductor is an insulator and offers resistance to the flow of current. This oxide coating can be removed by a thorough brushing with a wire brush. Since new oxide begins forming at once, the cleaned surface must be protected by a coating of corrosion inhibitor applied to the conductor either before or immediately after wire brushing.

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Corrosion Inhibitors

Many different compounds are sold under various trade names for the prevention of corrosion at connections and splices. The simplest form is a grease, such as petrolatum, which merely seals out moisture and air from the joint. The use of additives or special processing increases the life of the compound and prevents it from dripping away when hot. Some inhibitors are also offered as contact aids. In these, the addition of sharp metallic particles to pierce the aluminum oxide or an ingredient to dissolve the oxide assist in obtaining a lower contact resistance. Although these compounds assist in penetrating the oxide layer, they should not be used as a substitute for brushing but as a supplement to brushing.

The oxide coating is especially troublesome on conductor underneath armor rods. When a new transformer installation is made on an existing line, it is quite difficult to get a good connection for the hot-line clamp without removing the armor rods and brushing the conductor. A somewhat easier solution is the installation of short tap armor rods on a newly-cleaned spot on the conductor beyond the existing armor rods. Failure to obtain a good contact between armor rods and conductor or between hot-line clamp and armor rods can cause excessive light flicker, radio noise, and burning of the conductor.

CHAPTER

SPECIAL TRANSFORMERS

Autotransformers

An autotransformer is a transformer in which a part of the winding is common to both the primary and secondary circuits.

For some uses, an autotransformer provides a satisfactory and less expensive installation than a two-winding transformer. As a general rule, such uses are limited to transformation ratios of 2:1 or less. As an example, an autotransformer is suitable for a 14,400 volts to 7,200 volts transformation but is not satisfactory for transformation of 14,400 volts to 2,400 volts or of 7,200 volts to 120 volts.

Autotransformers are useful on circuits operating with two different primary voltages as might occur when the circuit has been partially converted from 7.2/12.5 kv to 14.4/24.9 kv. Where the transformation ratio is 2:1 or less, an autotransformer is smaller, costs less, has a higher efficiency and has less voltage drop than a two-winding transformer of the same capability. They can be installed as:

1. Single-phase autotransformer on single-phase line
2. Single-phase autotransformer on one phase of a three-phase line (REA Drawings VG151-25R and VG152-25R)
3. Bank of three single-phase autotransformers
4. Three-phase autotransformer

Single-phase autotransformers are generally recommended rather than three-phase because of the greater flexibility obtained. Although there is little or no price advantage in the smaller sizes, the larger sizes of three-phase autotransformers may show a sufficient saving over single-phase autotransformers to justify their use.

Three-phase banks should be connected in wye with the neutral point solidly connected to high and low side system neutrals.

Dual-Voltage Transformers

When a distribution system is converted from one primary voltage to another, the biggest cost is that of replacing distribution transformers. A large utility, converting its system gradually over a period of several years, may be able to move its transformers around so that it is faced neither with the need for large purchases of new, higher voltage transformers nor with the junking of many

older transformers. Rural systems, however, are usually so small that any practicable conversion of voltages must involve a considerable portion of the system. Careful planning is essential if excessive transformer costs are to be avoided.

Dual-voltage transformers, which can supply power from either the existing or the new primary voltage, can be used to smooth this changeover. The cost is not much more than that of a single-voltage transformer for the higher voltage.

A period of months or even years may pass between the time of decision to convert to a higher voltage and the actual start of conversion. If, during this time, dual-voltage transformers are purchased for normal replacements, both the number of new transformers to be purchased at time of conversion and the number of old transformers to be junked will be reduced. Dual-voltage transformers also make possible a reduction in the outage time during switchover.

If, however, dual-voltage transformers are installed too far ahead of the time of conversion, any savings may be cancelled out by the higher carrying charges. Generally, three to five years is the maximum time that a dual-voltage transformer should be installed prior to conversion. A careful economic study should be made before any such program is begun.

Regulating Transformers

Step voltage regulators normally furnish the voltage control needed on rural systems. Occasionally, either because of the characteristics of the line or of the load, a more localized "spot" regulation of voltage is needed. This might be at a small town or other concentrated load at the end of a long line, or at a radio station requiring a very narrow band of voltage swing. In such spots, it is often possible to obtain the necessary regulation at a lower cost through use of regulating distribution transformers or secondary voltage regulators.

Regulating transformers in sizes suitable for pole mounting are a relatively new development although the principle of tap changing under load has long been used in power transformers. Changing of high voltage tap positions on a standard transformer is done manually when the transformer is not energized. In the regulating transformer, this is done while the transformer is carrying load. The changing is done by motor in response to the control device which senses the output voltage of the transformer.

In addition to "spot" application, there may possibly be instances where an entire feeder can be regulated more economically with regulating transformers or secondary regulators than with primary

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voltage regulators. Such an installation should be undertaken, however, only after a careful study of all factors including first cost, maintenance costs, and quality of regulation.

Pad Mounted Transformers

The move toward underground distribution is not as rapid in rural areas as in cities, but there is every reason to expect that all power distributors will be called on to furnish more and more underground service. Bringing the transformers for such a system down to or below ground level presents several specialized problems. There is concern for the safety of the general public as well as for the lineman. The transformer must either have a pleasing appearance or be out of sight. Finally, the transformer must be able to supply its load under conditions less favorable than at the top of a pole.

Pole-type transformers can be used with suitable enclosures; and for a system having only a few underground services, this is probably preferable to the purchase of special transformers.

Where a number of transformers are needed and particularly where sizes of 25 kva and larger are used, special pad mounted transformers should be considered. These usually have the same core and coil units used in pole-type transformers but have special tanks and metal enclosures to cover all live parts.

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